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13.3: Accurate Representation of Attenuation in Large - Signal Helix TWT Simulation Codes†

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Abstract: *We report on the results of a comparison study of the CHRISTINE 1D helix TWT simulation code with the small signal theory of a beam interacting with a slow wave supported by a sheath helix in the presence of loss, in order to ascertain whether attenuation is treated with sufficient accuracy by the ad hoc model used in the CHRISTINE code. This study was motivated in part by the fact that losses in both dielectrics and in metals generally increase with increasing operating frequency, making the accuracy of the CHRISTINE code a potential concern for mm-wave helix TWT design. The basic conclusion of this study is that the existing model of attenuation in CHRISTINE is sufficiently accurate for attenuation rates up to a few dB/pitch. For larger attenuation rates, accuracy can be further improved by taking into account the (quadratic) dependence of phase velocity on the attenuation rate.*

Keywords: TWT; simulation; attenuation.

Large signal helix TWT simulation codes like CHRISTINE [1] represent circuit attenuation by the inclusion of an ad hoc term in the wave equation,

$$\frac{da_\omega(z)}{dz} + \alpha_\omega a_\omega(z) = \text{interaction terms} \qquad (1)$$

where $a_\omega(z)$ is the circuit mode amplitude at frequency ω as a function of distance *z* along the interaction space, and α_ω is the user-specified attenuation rate for the cold circuit (no beam present). Eq.(1) is derived under the assumption that the amplitude $a_\omega(z)$ changes very little over a helix period. The 'interaction terms' on the right hand side of (1) are the projection of the cold circuit electric field on the AC beam current. These terms depend on the transverse wavenumber $\kappa \equiv \sqrt{k^2 - (\omega/c)^2}$, where k is the axial wavenumber of a wave of frequency ω propagating on the cold circuit. The CHRISTINE code makes the approximation that κ may be evaluated with sufficient accuracy by ignoring the imaginary part of the wavenumber *k*.

This has the practical computational advantage that the Bessel functions that appear in the expression for the cold circuit electric field on the right hand side of (1) must be evaluated only for real values of their arguments.

We have tested the approximate representation of attenuation in CHRISTINE for a large range of attenuation rates by comparing results from the CHRISTINE code with results from an exact formulation of the theory of the interaction of a beam with the fields of a sheath helix surrounded by a lossy dielectric. The exact theory does not make the assumption that the wave amplitude varies slowly with z, nor does it make any approximation in the evaluation of the transverse wavenumber. Sample results from this comparison are shown below.

Figure 1 is a plot of the cold circuit attenuation rate $\alpha = \mathrm{Im}(k)$, expressed in units of dB per helix period, as a function of the loss tangent of the supporting dielectric sleeve.

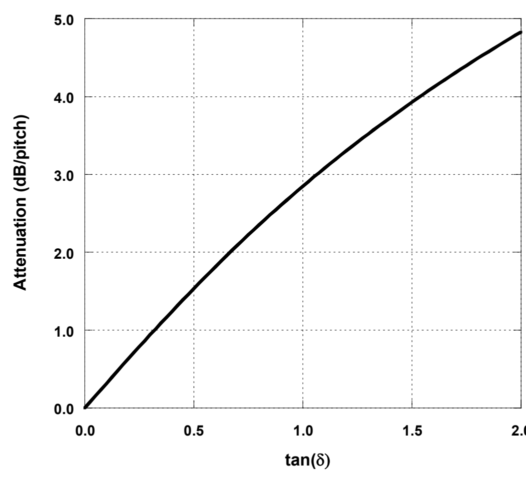

Figure 1. Cold circuit power attenuation rate as a function of the loss tangent of the cylindrical dielectric sleeve supporting a perfectly conducting sheath helix. Helix radius = 0.049"; outer wall radius = 0.110"; helix pitch = 0.03155"; real part of dielectric constant = 1.30.

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This plot is obtained from a numerical solution of the sheath helix dispersion relation with no beam present. (Note that attenuation rates near a sever can reach peak values of 25 dB/pitch or more, over a distance of a few pitches.) Values of the other parameters for this example are given in the figure caption. The values of cold circuit attenuation α_{ω} from Fig.1 are provided to the CHRISTINE code as input data.

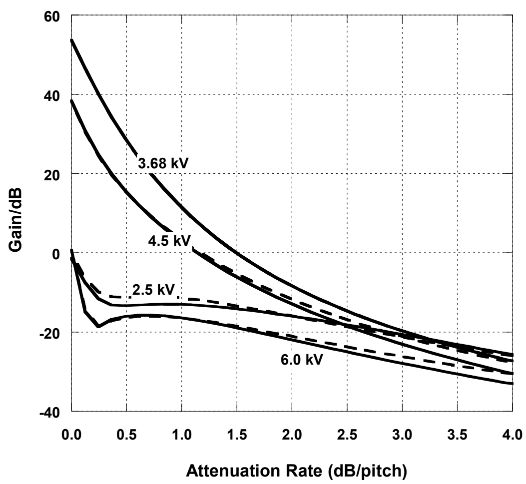

Figure 2: Small signal gain as a function of cold circuit attenuation rate, for various values of beam voltage, from exact linear theory (solid lines) and from the CHRISTINE code (dashed lines). Beam current = 0.170A; beam radius = 0.020". Interaction space length = 3.770". signal frequency = 5.0 GHz.

Figure 2 shows a comparison between the calculation of small signal gain from CHRISTINE and that from the exact linear theory, for various values of beam voltage. These results show that for this case the existing model of attenuation in CHRISTINE remains accurate for very large attenuation rates, including those that may be encountered near a sever. Our presentation will include additional comparisons between CHRISTINE and linear theory, including comparisons of the predicted dependence of the gain on beam voltage and on frequency, for various values of the cold circuit attenuation rate. We find that for a large range of attenuation rates, frequencies, and beam voltages the CHRISTINE model provides excellent accuracy, comparable to that illustrated in Figure 2. For very large values of attenuation rate, accuracy can be further improved by taking into account the (quadratic) dependence of phase velocity on the attenuation rate in the CHRISTINE code.

Reference

1. T.M. Antonsen, Jr. and B. Levush, "CHRISTINE: A Multi-frequency Parametric Simulation Code for Traveling Wave Tube Amplifiers," NRL report NRL/FR/6840-97-9845 (1997).